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3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

Fast Technology GmbH,
Feringastr. 6,
85774 Unterfoehring,
Germany.

Patents ADP number *(if you know it)*

7719990001

If the applicant is a corporate body, give the country/state of its incorporation

Germany

4. Title of the invention

Transducer Element

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Lloyd Wise, Tregear & Co.,
Commonwealth House,
1-19 New Oxford Street,
London WC1A 1LW.

Patents ADP number *(if you know it)*

117001

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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11. I/We request the grant of a patent on the basis of this application.

Signature Lloyd Wise, Tregear & Co. Date 12th August 1999

12. Name and daytime telephone number of person to contact in the United Kingdom

J. W. Bluff
(0171) 571-6200

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Title: Transducer Element

This invention relates to a transducer element suitable for use as a torque or force sensor transducer and to a transducer assembly incorporating the element.

One approach to non-contactless sensing of torque in a shaft rotating about its axis is a torque sensor based on magnetoelasticity. A magnetoelastic transducer element is secured to or integral with the shaft, the torque in which is to be measured, and a torque-dependent magnetic field emanated by the transducer element is detected by a sensing device external to the shaft and responsive to magnetic fields. Examples of sensing devices are a Hall effect device, a saturating coil sensor, or various of other magnetic field sensitive devices known in the art.

Magnetoelastic transducer elements form a ring or annulus which is circumferentially magnetised. The field forms a closed loop normally contained within the element.

One form of transducer element is a separate ring of magnetoelastic material attached to the shaft such as disclosed in U.S. patents 5,351,555, 5,465,627 and 5,520,059, all to Garshelis and assigned to Magnetoelastic Devices, Inc. In the ring transducer elements, the ring supports a circumferential magnetic field which is confined within the ring, that is no field is detectable externally in the absence of torque. When torque in the shaft is transmitted to the magnetoelastic ring, an external magnetic field is emanated and is detected by a sensor arrangement.

A different approach to providing a circumferentially

magnetised magnetoelastic sensor is disclosed in International Patent Application PCT/GB99/00736 (published on under the number) in which the transducer element is an integral portion of the shaft whose torque is to be measured. This avoids problems in securing a separate ring properly to the shaft. An integral transducer element approach is also disclosed in published International Patent Applications WO99/21150 and WO99/21151.

Magnetoelasticity is a phenomenon which, as yet, is apparently still not fully understood and explained. It is, therefore, generally desirable to find other forms of magnetisation that might be employed in transducer elements, particularly suitable for torque sensing.

A disadvantage of torque transducer elements that are circumferentially magnetised is that it is difficult to calibrate the sensor system with respect to short term field variations with temperature or longer term changes of the magnetic field.

A transducer element which produces no reliably detectable field under no torque presents a calibration problem. In a preferred sensor system described in PCT/GB99/00736 (WO), the shaft is directly magnetised in three or more regions along the axis. Taking the case of three regions, an inner region is circumferentially magnetised with one polarity and it is flanked by respective outer regions magnetised with the opposite polarity of circumferential magnetisation. The

inner region provides a transducer element, the two adjacent outer regions acting as guard and keeper regions. It is preferred that the regions be magnetised deeply into the shaft requiring a strong applied field for larger cross-section shafts.

According to a first aspect of the present invention, one or more magnetic transducer elements are provided integrally in a shaft of magnetisable material but using longitudinal magnetisation, that is a magnetisation that lies in an axial direction in contrast to circumferential magnetisation.

More particularly, the provision of three or more longitudinally magnetised regions having an inner region flanked by two regions of opposite polarity to the inner region enables the inner region to be used as the transducer element while the two flanking regions act as guard or keeper regions for it. Additional regions of alternating polarity may be provided to act as further keeper and guard regions. These additional regions help maintain the magnetisation of the transducer region, especially where the device is used in the presence of strong magnetic fields. Present investigations have indicated that the invention can be practised irrespective of whether the material exhibits magnetoelasticity though many materials will do so in any event. It is a feature of the longitudinal magnetisation proposed that a magnetised region will exhibit a fringing field external to the shaft whose direction is a function of torque and

which can be used as a reference for calibration purposes. The invention may be practised with a magnetisation that is essentially confined to an annular surface zone of the shaft.

The present invention also includes the concept of measuring the bending force or the shear force in an elongate member subject to a bending or shearing moment. For convenience all such elongate members, subject to torque, bending and/or shear forces, whether intended for rotation or not, will be referred to as "shafts". The invention will be mainly discussed and described in relation to a shaft rotatable about a longitudinal axis to transmit torque applied to a driven end of the shaft to a load coupled to the other end. However, it will be understood that torque measurement can be required in some circumstances where the load end of the shaft is effectively fixed and forces inducing torque are applied at the other end.

The invention will also be discussed and described in relation to a shaft of solid circular cross-section. It will be understood from what follows that the shaft may be of other cross-sectional shape as regards its circumference and that non-solid sections may be usable in the practice of the invention.

In a further development of the invention the transducer element may be formed in a plate or disc in which at least one major surface of the plate or disc is cooperable with a magnetic field sensor arrangement.

According to a second aspect of the present invention, a member is provided about an axis to transmit torque or force between the member and the axis, the member having an outer annular magnetised region encircling the axis and an inner annular magnetised region of opposite polarity to the outer annular region to generate a magnetic field component which is a function of torque or force.

Aspects and features of the present invention for which protection is sought are set out in the accompanying claims.

In order that the present invention may be better understood, embodiments of it will now be described with reference to the accompanying drawings, in which:

Fig. 1 diagrammatically shows a torque sensor system for a shaft having three longitudinally magnetised regions;

Figs. 2a and 2b show a transverse and an axial cross-section respectively through the inner region, and Figs. 2c and 2d show a circuits for cancelling the effect of an ambient external field;

Figs. 3a and 3b show the shaft of Fig. 1 under torque;

Figs. 4a and 4b are vector diagrams relating to the external magnetic field of the inner region;

Fig. 5 shows a modification in which the shaft has four longitudinally magnetised regions;

Fig. 6 shows a magnet arrangement for magnetising the

shaft regions, and Fig 6a shows an arrangement for magnetising three regions simultaneously;

Fig. 7a illustrates the magnetic flux associated with a longitudinally magnetised region by way of explanation;

Fig. 7b shows in cross and axial sections the toroid of magnetic flux established within the region shown in Fig. 7a;

Fig. 8a and Fig. 8b illustrate a two-phase magnetisation procedure for obtaining an annular zone of magnetisation within a deeper region of magnetisation;

Fig. 9 shows another magnetising arrangement for the shaft using a solenoid-like coil;

Fig. 10 shows how the invention is applicable to shear force measurement;

Fig. 11 shows a side view of another embodiment of the invention using a disc-like member in which the transducer element is formed;

Fig. 12 is a view of the transducer assembly side of the disc seen in Fig. 11;

Fig. 13 is a vector diagram showing radial and circumferential fields;

Fig. 14 is a modification of the embodiment of Fig. 11;

Fig. 15 is a view of another embodiment of the invention using a disc-like member in which the transducer element is formed, and Fig. 15a shows a cross-section through the transducer of Fig. 15;

Fig. 16, 16a and 16b show the effect of a bending force applied to a shaft;

Fig. 17 shows an arrangement of sensors to detect both an applied torque and a bending force.

Figs. 18 to 20 show an alternative example of the present invention and the effect of forces thereon.

Fig. 1 shows a solid shaft 10 of circular cross-section and of a magnetisable material rotatable about longitudinal axis A-A and having three contiguous or closely adjacent regions 20, 22, 24 that are magnetised in the longitudinal (axial) direction as shown by the arrows. The regions are shaded for clarity of illustration. They are integral portions of the shaft. These regions are magnetised with alternating polarity so that adjacent regions present like poles to one another, e.g. N to N and S to S as indicated. In each region, the magnetisation extends in an annular zone around the shaft circumference. The regions are close enough that the poles exercise a mutual repulsive effect on the flux emanated thereby.

The manner in which magnetisation is obtained is also discussed further below.

Fig. 2a shows a transverse cross-section through the shaft at the inner of the regions 22 and Fig. 2b shows an axial or diametric section illustrating the magnetisation in that region and the flux generated by it. The nature of the internal magnetisation is discussed more fully below with reference to Fig. 7. Fig. 2a shows diagrammatically that the magnetisation is established predominantly in an annular zone 26 at the surface of the shaft, the magnetisation being in the same axial direction (normal to the plane of the drawing) around the

circumference.

Fig. 2b shows an axial section illustrating that in closing the flux lines associated with zone 26 most of the magnetic flux is going to be internally confined as indicated at Mi within the relatively high permeability shaft material, assuming the shaft is solid or substantially so. A central axial bore through the shaft is of little effect since the axial core material sustains little if any flux. Fig. 2b also shows that some magnetic flux Mf links the poles of zone 26 as an external fringing flux outside the shaft. The exterior is assumed to be a low permeability air path. A component of the fringing flux Mf is detectable when torque is applied by non-contacting sensor devices 30a and 30b placed exterior to the surface of shaft 10. Across any diameter, zone 26 will include two portions 26a and 26b, which although magnetised in the same axial direction will result in a different sensor output as is discussed below. As will also be further discussed below, the magnetic field associated with region 22 may be considered as having a toroidal shape coaxial with the axis of rotation A-A.

While a single region 22 of magnetisation could be usable alone, it is preferred to have it flanked by adjacent regions 20 and 24 of opposite polarity where the mutually repulsive effect of like poles assists in forcing the provision of fringing flux Mf from the region 22. The regions 20 and 24 also assist in stabilizing the longer

term magnetisation of region 22. The region 22 will hereinafter be referred to as the transducer element or region. The regions 20 and 24 will be referred to as keeper and guard regions. In another embodiment to be described, more than three axially disposed regions of alternating polarity can be employed, where inner regions can serve both as transducer elements and as keeper or guard regions.

While Fig. 1 shows the shaft 10 under zero-torque, Figs. 3a and 3b show the shaft when under a clockwise torque (arrow CW) and under a counterclockwise torque (arrow CCW) as seen from the right hand end. The shaft may be rotating, e.g. transmitting load, or static, e.g. fixed at the left hand end. In conjunction with Figs. 3a and 3b, Figs. 4a and 4b are vector diagrams of the fringing field Mf from zones such as 26a and 26b in Fig. 2b. In the absence of torque in the shaft the field Mf in each zone lies parallel to the axis with the same polarity. There is no component of the field in the circumferential direction.

What is of still more interest is what happens to the field established in the shaft, and more particularly the detectable field exterior to the shaft under applied torque. Experiments on a Cobalt steel shaft have demonstrated that as the shaft is placed under torque, a circumferentially directed field component is generated by the transducer region, e.g. 22, having a magnitude and direction dependent on the applied torque and its

direction. Furthermore, this component is measurable to provide the basis of a torque sensor arrangement. There follows a discussion of the present understanding of external fields created under torque. This explanation takes no account of any magnetoelasticity that the shaft may exhibit.

Under torque the shaft itself will be twisted about its axis so that, for example, a line parallel to the axis of rotation A-A drawn along its surface will deflect. Likewise the magnetic field is deflected as illustrated by the arrows in Figs. 3a and 3b.

Fig. 4a shows a deflected field vector Mf′ directed at an angle θ with respect to the no-torque field Mf. (The skew is exaggerated for clarity of illustration.) The field vector, Mf is resolvable to orthogonal components: component Ms in the circumferential direction, i.e. tangential to the shaft, and an axial component in the direction of zero torque field Mf. The component Ms is both torque dependent and measurable. The same vector diagram applies to any small lengthwise portion of zone 26, when seen from a point perpendicularly above the surface. Fig. 4b shows the complementary result when the torque is in the opposite direction. The component Ms is now in the opposite direction. However, if the shaft is considered from a fixed point, say perpendicular above zone 26a, the vector diagram of Fig. 4a applies for the CW torque but from this perspective the vector diagram of Fig. 4b applies for the zone 26b. Thus

looking at the section of Fig. 2a the components Ms generated in diametrically opposed portions have opposite directions. Advantage can be taken of this in cancelling the influence of an external field discussed below.

A practical torque sensor requires the transducer element which responds to the torque in the shaft and a sensor device arrangement together with appropriate circuitry for deriving a signal output representative of torque. Many types of sensing device responsive to magnetic fields are known including coils, and particularly saturating inductor devices, Hall effect devices and magnetoresistive devices. For the purposes of implementing the present invention it is preferred to use devices which are sensitive to the direction or orientation of the magnetic field to be measured. More particularly, saturating inductor type devices may be used. An example of such devices and a signal conditioning and processing circuit for use therewith is described in published International Application WO98/52063.

Fig. 1, Fig. 2a and Fig. 2b show a pair of sensing devices of the saturating inductor type, 30a and 30b, which are disposed diametrically opposite one another adjacent the shaft 10, within the axial limited defined by the boundaries of transducer region 22 so as to lie within its fringe field. The axis of response of each sensing device 30a and 30b is aligned with the direction of the circumferential field component Ms. A further sensor

device 32 of the same type shown in Fig. 1 is disposed adjacent transducer region 22 but is aligned axially to respond to the fringe field Mf. The sensors are non-contacting with respect to the shaft 10.

In Fig. 2a it is seen that looked at from a given direction external to the shaft 10, e.g. from the left in the figure, the respective field components Ms in any two diametrically opposite zone portions such as 26a and 26b are oppositely directed whereas an ambient external magnetic field E, such as the Earth's magnetic field, is in the same direction at both sensing devices. The provision of a pair of oppositely directed sensing devices for the diametrically opposite components Ms can be arranged to add the Ms components while cancelling out an external field such as E. This is illustrated by the circuit of Fig. 2c where the two sensing devices 30a and 30b oriented to align with the Ms components and are connected to processing circuit 36 to add the Ms components while cancelling the external field. It will be appreciated that depending on the type of sensing device and the manner in which individual devices are utilised as regards their signal output, each device may have individual drive/sensing circuitry associated with it, together with signal combining circuitry to obtain the required output.

Torque measurement made by use of a longitudinally magnetised transducer region also provides an additional benefit as compared with the prior published

magnetoelastic torque sensors using circumferentially magnetised regions in which the field is confined within the transducer element at zero torque. The fringe field can be detected by means of the separate axially-oriented sensing device 32. This may be a device such as 30a or 30b but oriented perpendicularly thereto in the axial direction. The sensing device 32 provides a signal indicative of the quiescent, no-torque, state of the shaft 10 and provides a reference or calibration value to processing circuit 36 against which to compare the torque-dependent Ms component. Should the magnetisation in the region 22 change, specifically deteriorate over time, the Mf and Ms values will be affected in equal proportion and the Ms value compensated accordingly.

The compensation for external fields described with reference to Fig. 2c can be extended to fields from any direction by the arrangement shown in Fig. 2d.

In Fig. 2d the pair of sensors 30a and 30b are connected in series with a second pair of sensors 30c and 30d, also arranged on opposite sides of the shaft 10 but disposed orthogonally with respect to the sensors 30a, 30b. The four sensors are connected in series as shown for connection to appropriate processing electronics 36. It will be seen that, as in Fig. 2c, the Ms components in sensors 30a, 30b will add while an external field E_1, will be cancelled. Likewise Ms components acting on sensors 30c, 30d will add, and will also add in the series circuit with respect to the Ms components at sensors 30a, 30b. A

field E_2 orthogonal to E_1 will be cancelled in the sensors 30c, 30d. An external field from any direction will cancel, as it can be considered as comprising orthogonal components in the E_1 and E_2 directions.

There are two further developments of the sensor system thus far described. One is the use of more than three adjacent magnetised regions. Fig. 5 shows four such regions 40, 42, 44, 46 along the shaft axis with neighbouring regions closely adjacent. The four regions are longitudinally magnetised with alternating polarity. In this embodiment, the two inner regions 42, 44 are used as transducer elements being provided with respective sensing devices 48a and 48b (which may be diametrically opposite pairs as already described) located within the axial limit set by the boundaries of the respective regions. It is seen that the exterior regions 40 and 46 act as guard/keeper regions while inner transducer regions 42, 44 also act as respective guard keeper/guard regions for one another. The sensing devices 48a, 48b are oriented transversely with respect to the axis, i.e. comparable to Fig. 2a, so as to respond to the Ms components.

One application of two inner transducer elements of opposite polarity in cancelling out the effect of an external field, is where access to the external field M_f may be practicable only on one side of the shaft. In this case the devices 48a, 48b on the same side of the shaft will be subject to Ms components of opposite polarity from

regions 42 and 44 when the shaft is under torque. However, an ambient field such as the Earth's field is in the same direction at both. Thus by analogy to Figs. 2a and 2c, the Ms components can be added while cancelling the ambient components. If room permits, an orthogonal arrangement such as in Fig. 2d can be employed.

The magnetisation of each longitudinally magnetised region can be done with what amounts to a horseshoe or U-shape magnet 50 of sufficient power as shown in Fig. 6. The magnet pole faces facing the shaft can be made concave to better conform to the shaft. The magnet 50 can be realised with permanent magnets or preferably an equivalent electromagnet. The latter has the advantage of providing greater control over the strength of the magnetising field. To obtain longitudinal magnetisation over an annular zone around the shaft 10, magnet and the shaft are rotated relative to one another about the axis A-A of the shaft. The magnetisation is performed with a field strength sufficient to saturate at least the surface zone of the material as indicated at 52 so that the material is left with a magnetisation equal to its remanence value. The magnetisation need not extend too deeply since the fringing flux external to the shaft will be predominantly generated from near the surface. However, there is a deeper magnetisation technique which may be beneficial in obtaining output signals with a minimum of noise.

Fig. 6a shows a development of the magnet 6 to allow

a number of regions to be magnetised simultaneously with alternating polarity of magnetisation. As shown in Fig. 6a the magnet structure enables a common magnet leg to be used jointly for two adjacent magnets. Fig. 6a shows a structure specifically for magnetising three regions simultaneously.

Fig. 7a illustrates a surface adjacent annular zone such as indicated in Fig. 2a, in a region longitudinally magnetised as already described. Fig. 7a shows the annular zone represented in any diametric cross-section as magnets NS in which the flux paths are predominantly closed within the interior of the material. The exterior fringing flux is not shown here. According to this explanation it is reasoned that the flux will exist as a toroid of flux lines as shown in Fig. 7b, the cross-section at the left indicating flux in the opposite directions by different shadings.

The flux pattern illustrated in Fig. 7a may be referred to as a one or single phase magnetisation. It may be desirable, for greater certainty and control of measurement, to undertake a two phase magnetisation procedure in which the state of magnetisation of the cross-section of the shaft is better defined. This is illustrated in Fig. 8a which shows a first phase of deep magnetisation of the shaft to produce a given axial polarity of magnetisation.

The deeper magnetisation requires a stronger applied magnetic field so as to leave a greater depth of material

left with remanent magnetisation. A second phase of magnetisation is then undertaken by applying a magnetic field of opposite polarity to that of the first phase and whose strength is chosen so as to leave an outer annular zone of one polarity and an inner annular zone of opposite polarity as illustrated in Fig. 8b. The two annular zones close their magnetic flux paths through one another, aiding in achieving a stable, well defined magnetic state. The magnetic flux lines again define a toroid within the shaft. A stable well-defined external fringing flux will be established.

The explanation given above applies generally to magnetisable materials. However, it will be recognised that the performance of magnetic materials to achieve the desired results will vary.

The permeability, remanence and, particularly for two phase magnetisation, coercivity of the material are all relevant. Satisfactory experimental results have been achieved with steels containing a percentage of Nickel, and if possible also cobalt. In practical situations, the design of and choice of materials for a torque transmitting shaft may largely depend upon other mechanical engineering operating environmental considerations.

Fig. 9 illustrates another magnetising arrangement which may be used to magnetise a shaft in a single or a two phase manner. In Fig. 9 the shaft 10 is enclosed by a coil 60 coaxial with the shaft in the manner of a

solenoid coil. The coil will have an axial dimension appropriate to the axial length of the region to be magnetised. Energising the coil from a current source (I) generates a longitudinal magnetic field to longitudinally magnetise the region within the coil, the polarity of the current in the coil determining the polarity of the magnetisation.

The depth of magnetisation is controllable by controlling the strength of the current I. This control can be exercised to perform two phase magnetisation. For example a coil for magnetising a steel shaft in accord with Fig. 8a was energised with a direct current of 20A for the first phase and a current of opposite polarity of 5A for the second phase..

A coil coaxial about the shaft can also be used as a sensor coil. In this case the coil may be the same as that used to magnetise the shaft, but preferable is one of much finer gauge wire than is required to carry a magnetising current.

The present invention may also be employed to measure other forces, such as measurement of a bending force, or of shear force imposed in a load bearing structure.

A force such as a bending or shear force will result in a distortion of the magnetic field around the shaft. For example, as shown in Fig. 16, a bending force may act to stretch the upper part of the shaft and compress the lower part of the shaft, resulting in a non-uniform fringe flux, for example as shown in Figs. 16a and 16b. By use

of appropriately positioned sensors, variations in the magnetic field can be measured, and from this a determination of the applied forces made. For example, if a bending force in one direction is to be determined, two sensors will be required in this direction. Three or more sensors will be required to determine a bending force in two directions.

As shown in Fig. 17, if four magnetic field sensors 160a, 160b, 161a, 161b are used, averaging the magnetic flux measured by the four sensors will determine the applied torque, and the difference between the measured flux of sensors 160a and 160b and sensors 161a and 161b can be used to determine the vertical and horizontal bending forces respectively.

Fig. 10 shows a member 70 secured at a point 72 along its length and supporting a load L at another point 74. The member 70 is longitudinally magnetised to provide a transducer region 76 in the manner of region 22 described above. The region 76 is located so as to be responsive to the shear forces. Shear forces generated in the region 22 will tend to cause a deflection of the direction of the magnetic field Mf creating transverse component Ms as a measure of the force acting on the member 70.

Another aspect of the invention is the measurement of torque in a disc or similar plate-like part of magnetisable material.

Fig. 11 shows a diametric section through a circular disc 110 which is to be subject to torque about an axis A-

A. The disc is of magnetisable material, or at least the annular region 122 of it is. Adjacent its periphery the disc is magnetised through its thickness to have two radially spaced regions 112 and 114 of opposite polarity. This can be obtained by rotating the disc 110 between a pair of magnets (permanent or electromagnets) 116 and 118 with opposite poles facing each other through the disc. Thus each region 112 and 114 is an annulus of magnetisation. Together they provide a transducer element or region 122. To some extent the magnetic flux will tend to close in a loop including both regions, not unlike the toroidal flux pattern of Fig. 8b. This assumes the disc has a relatively high magnetic permeability. However, the analogy must not be taken too far since the magnetised region in Fig. 8b has high permeability regions either side of it whereas the overall annular magnetised region 122 is bounded by low permeability air at each side. Thus flux will emerge from the disc surface into the air medium. The performance of the sensor can be improved by profiling the disc such that the magnetised annular regions are thicker than the regions between them.

Further, by changing the profile of the annular regions in a circumferential direction, there will be a change in the magnitude of the magnetic field as the disc rotates. This can be used to detect rotational velocity of the disc.

Fig. 12 shows a view of one surface 111 of the disc with the regions 112, 114 shown in hatched line. It will

be seen that the magnetic flux exterior to the surface and linking regions 112 and 114 will lie radially. This flux is indicated as Mr in Fig. 13. Consider now a use for the disc in which it is being used to transmit torque from a shaft 120, to which it is secured to rotate therewith about axis A-A, to provide drive at the periphery of the disc, formed as a gear wheel 124 for example. The torque transmitted through the disc will tend to deflect or skew the radial field component Mr shown in Fig. 13 to be slightly offset from the radial direction as indicated by Mr'. Mr' can be resolved into a radial component and orthogonal component Ms acting in a circumferential direction with respect to annular sensing region 122. This is similar to what was explained with reference to Figs. 4a and 4b. The magnitude and direction of Ms is dependent on the magnitude and direction of the applied torque. This situation would apply equally to the transmission of drive was from the outer periphery of the disc to the central shaft.

Referring again to Fig. 12 the radial field Mr can be detected by a sensor 126 radially oriented, and the Ms component measured by a sensor 128 at right angles to the radial direction. These sensors will be placed in fixed positions with respect to the disc rotating past them in non-contacting fashion.

Depending on the drive arrangement and the distribution of stresses in the disc more pairs of non-contacting sensors 126, 128 may be provided angularly

displaced around the disc. Fig. 12 shows four such pairs of non-contacting sensors.

It will also be apparent that the torque sensor arrangement described can be used to measure torque in the shaft 120 communicated to the disc when the outer periphery is held fixed or say under a braking force, or when torque is applied to the periphery and the shaft 120 is fixed or braked.

The orientation of a pair of diametrically opposite Ms sensors 128a, 128b produce Ms components of like orientation to the Ms components in Fig. 2a so that the sensors can be connected to add as far as Ms components are concerned but cancel the effects of an external field. The use of four sensors 128a-d in two orthogonally arranged pairs enables the cancellation of external fields from any direction while adding the Ms components similarly to the arrangement of Fig. 2d.

The use of multiple radial sensors 126 for the reference components Mr, particularly four sensors in two orthogonally arranged pairs, also enables connection in a manner providing cancellation of any external field. The sensor devices for the transducer assembly are to one side of the disc 110. The magnetic efficiency can be enhanced by closing the magnetic path on the other side by a member providing an annulus of high permeability material to bridge regions 112 and 114.

In the embodiment of Figs. 11 to 13, the disc is directly used as a load transmitting member. A disc or

other plate-like member appropriately magnetised may also be used for torque measurement by securing the disc or plate to a load transmitting part or any part subject to a torque in its operation. For example Fig. 14 shows a part 130 which is revolving about an axis A-A so as to create a torque in the part. The part has a surface 132 at which the stresses due to the torque are expressed and a disc 134 of the kind shown in Fig. 12 is affixed to the surface 132. The disc 134 must be securely fixed to the surface, e.g. by screws 136, both radially inwardly and outwardly of the sensor region 122 so that the stresses are accurately reflected in this region.

To improve the magnetic efficiency of the disc the non-sensor side can have the magnetic path at transducer region closed by at least an annulus 138 of high permeability material acting between regions 112 and 114. The part 130 may itself provide this function.

Additional radially spaced regions of opposite polarity may be provided on the disc. These additional regions can form keepers or guards as discussed above.

Fig. 15 illustrates how the disc-like torque transducer assembly can be adapted to work with circumferential magnetisation. Fig. 15 is a face view of a disc 150 through which torque is transmitted between a drive applied on the axis A and the periphery or vice versa as previously described. In this embodiment, there is a transducer region 152 which comprises an inner annular region 154 and an outer annular region 156. As

shown in Fig. 15a, the circumferential magnetisation may be applied through the face 158 using an appropriately polarised magnet 160 that is circumferentially arranged.

In the absence of torque the circumferential fields in regions 154 and 156 will be trapped within the annular regions. However, under torque the field becomes skewed in the manner well-known with prior art circumferential transducers, e.g. Garshelis U.S. patents 5,351,555, 5,520,059 and 5,465,627. The consequence is that at face 158 the regions 154 and 156 develop magnetic poles of opposite polarity. The polarity is dependent on the direction of torque.

A radial field Ms is generated externally of the surface 158 between regions 154 and 156, the radial magnetic flux being a function of torque. The radial flux can be sensed by sensors disposed as for the radial (reference) flux in Fig. 12. In contrast to Fig. 12 it is seen that the detectable torque-dependent flux is radial, rather than circumferential, but there is no reference field component available.

What may be conveniently called the disc form of implementing the invention provides the basis of implementing in an essentially planar form various configurations which are analogous to configurations implementable on a rotating shaft. The disc form may also be adapted for stress measurements other than torque. Various implementations of these ideas will now be described.

It has already been described with reference to Figs. 3 and 5 how the performance of a transducer region in a shaft can be stabilised and enhanced by neighbouring guard or keeper fields. A similar provision may be made with a disc.

With the disc arrangement generally as shown in Figs. 11 to 15, it is also possible to measure applied forces other than torque. A suitable arrangement is shown in Figs. 18 to 20. In this arrangement, a tube 170 is mounted on the disc around the outer magnetised region as shown in Figs. 18a and 18b. Forces applied to the axle will be transmitted through the disc to the tube 170 and vice versa. As shown in Fig. 19, when an axial force is applied to the axle or the tube 170, or a bending or shearing force is applied as shown in Fig. 20, mechanical stresses will be induced in the disc, resulting in a change to the magnetic flux, for example as shown in Fig. 20a. By detection of the changes in the magnetic flux by magnetic sensors as described previously, the nature and magnitude of these forces can be determined. It may be necessary to provide additional sensors to those required for measuring torque to measure these additional forces.

Claims

1. A transducer element for a torque or force transducer comprising

a member having an annular region of magnetisable material extending to an annular surface of the member,

said annular region being longitudinally magnetised such that deflection of the field under an applied stress transmitted to said transducer element generates a circumferential magnetic field component that is a function of the applied stress.

2. A transducer element as claimed in Claim 1 in which said member is adapted to have a torque applied thereto such that said circumferential magnetic field component is a function of torque.

3. A transducer element as claimed in Claim 1 or 2 in which said circumferential component is zero at zero applied stress.

4. A transducer element as claimed in Claim 1, 2 or 3 comprising a further annular region located inwardly of the first-mentioned annular region and longitudinally magnetised with the opposite magnetic polarity to that of the first-mentioned annular region.

5. A transducer element as claimed in Claim 1, 2 or 3 in which said member comprises at least one further annular region of magnetic material adjacent the first-mentioned annular region and extending to an annular surface, and wherein said at least one further annular region is longitudinally magnetised with a polarity opposite to that

of said first mentioned annular region.

6. A transducer element as claimed in Claim 5 in which there are two further annular regions on opposite sides of the first-mentioned annular region.

7. A transducer element as claimed in Claim 4 in which said member comprises at least one portion of magnetic material adjacent said transducer element, each guard portion comprising an annular outer region extending to an annular surface of the member and an annular inner region located inwardly of said outer region, said annular outer and inner regions being longitudinally magnetised and having opposite polarities of magnetisation to one another and respectively to the first-mentioned and further annular regions of said transducer element.

8. A transducer element as claimed in Claim 7 in which there are two portions adjacent said transducer element.

9. A transducer element as claimed in any preceding claim in which said member is a cylindrical body, preferably circular cylindrical, mounted for having torque applied about its axis.

10. A transducer comprising a transducer element as claimed in any preceding claim and a magnetic field sensor device disposed and oriented to detect said circumferential field component and provide a signal representing same.

11. A transducer as claimed in Claim 10 further comprising a magnetic field sensor device disposed and oriented to detect a longitudinal fringe field exterior to

the annular surface of the transducer element and provide a signal representing same.

12. A transducer as claimed in Claim 11 comprising a signal processing circuit responsive to the signals representing the circumferential field component and the longitudinal fringe field to produce an output signal representing the circumferential field component referred to the longitudinal fringe field component.

13. A transducer element for a torque transducer comprising a member at least a portion of which is magnetisable and within which there is a first magnetised annular region and a second magnetised annular region located inwardly of the first region, said first and second regions both being longitudinally magnetised with respect to the direction of an axis extending through the annular regions, and said first and second regions having their respective longitudinal magnetisations of opposite polarity, a surface or interface transverse to said axis at or adjacent which said annular regions terminate to provide a radially directed annular magnetic field extending externally of said surface or interface with respect to the transducer element, said radially directed magnetic field being deflectable in response to a torque transmitted radially through said first and second regions to produce a circumferentially directed magnetic field component that is a function of the torque.

14. A transducer element as claimed in Claim 14 in which said circumferential component is zero at zero torque.

15. A transducer element as claimed in Claim 14 or 15 in which said member is adapted as a load transmitting part capable of transmitting a rotational drive applied radially within said annular regions to a load applied radially without said annular regions or vice versa.

16. A transducer element as claimed in Claim 13, 14 or 15 in which said member is disc-shaped.

17. A transducer system comprising a transducer element as claimed in any one of Claims 13 to 16 and a magnetic field sensor device disposed and oriented to detect said circumferential magnetic field component and provide a signal representing same.

18. A transducer system as claimed in Claim 17 further comprising a magnetic field sensor device disposed and oriented to detect said radial magnetic field and provide a signal representing same.

19. A transducer system as claimed in Claim 18 further comprising signal processing circuitry responsive to said signals representing the circumferential magnetic component and the radial magnetic field respectively to derive an output signal representing the circumferential magnetic component referred to the radial magnetic field.

20. A torque or force transducer element

comprising a member adapted to transmit torque or force applied along, on or about an axis extending through the member to a portion of the member spaced from said axis, or vice versa,

said member having a surface transverse to said axis,

a first, outer, annular region encircling said axis located between said axis and said portion and extending to said surface, a second, inner, annular region located between said axis and said outer region and extending to said surface,

said first and second annular regions, being magnetised with opposite polarity

said surface cooperating to generate a magnetic field component which is a function of said torque or force.

21. A transducer element as claimed in Claim 20 in which said first and second annular regions are both longitudinally magnetised to develop a radial magnetic field component extending therebetween at said surface and a circumferential magnetic field component at said surface that is a function of torque.

22. A transducer element as claimed in Claim 20 in which said first and second annular regions are both circumferentially magnetised to develop a radial magnetic field component at said surface as a function of torque.

23. A torque or force transducer assembly comprising

first and second members coaxially disposed,

said first member being of greater diameter than said second member,

a disc-like member extending generally radially of said axis and connecting said first member to said second member for transmitting force from one member to the other, said disc-like member comprising two magnetised annular regions,

said magnetised regions having a magnetisation such that the regions cooperate to generate a magnetic field component that is a function of a stress established in transmitting a load between said first and second members.

24. A transducer assembly as claimed in Claim 23 in which said assembly is adapted to transmit torque from one of said members to the other.

25. A transducer assembly as claimed in Claim 23 in which said magnetised regions are longitudinally magnetised with opposite polarities or circumferentially magnetised with opposite polarities.

26. A transducer assembly as claimed in Claim 23 in which said first and second members are mounted to cause flexing of said disc-like member in response to relative axial displacement of the first and second members.

27. A transducer assembly as claimed in Claim 23 in which said first and second members are disposed to cause flexing of said disc-like member in response to a relative displacement of said first and second members away from axial alignment.

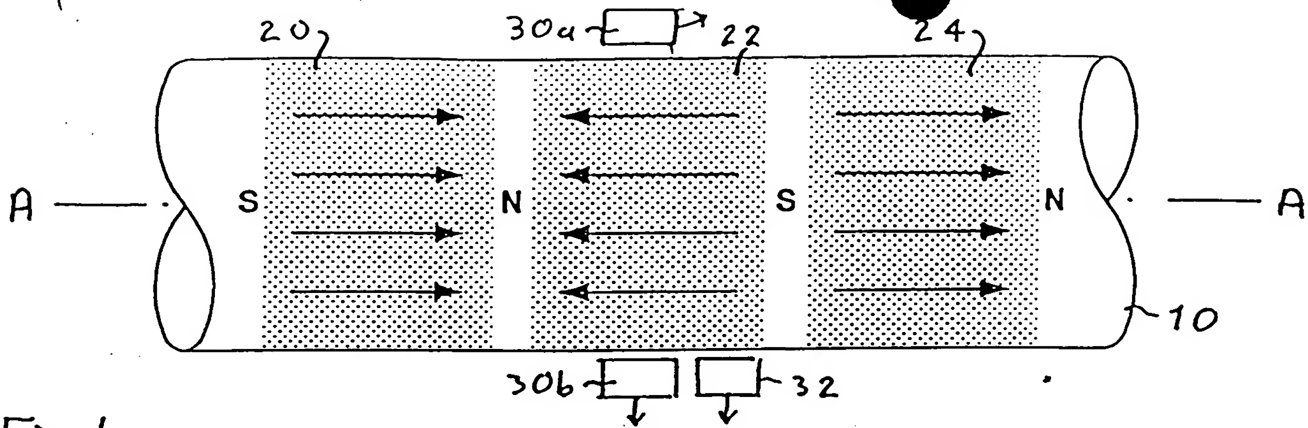


Fig. 1

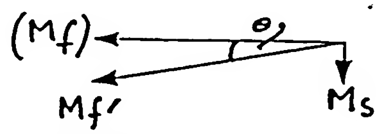


Fig. 4a

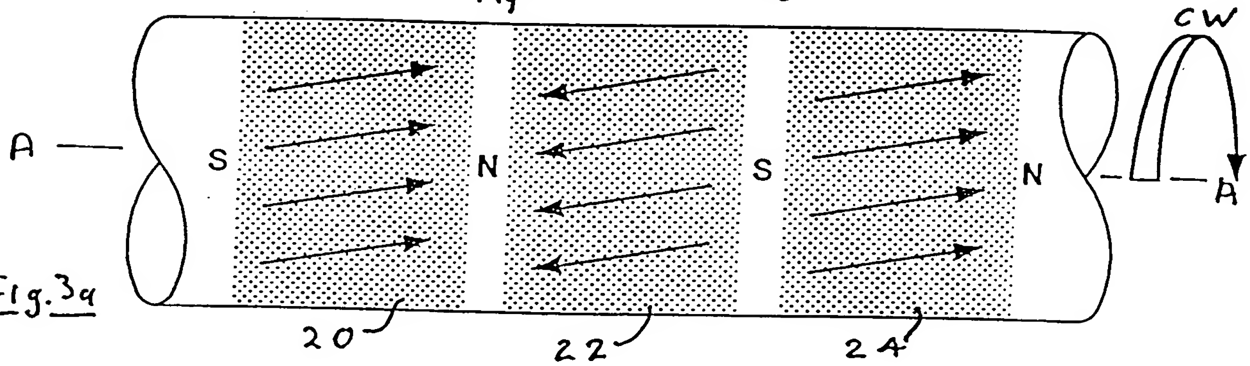


Fig. 3a

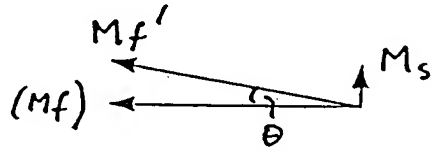


Fig. 4b

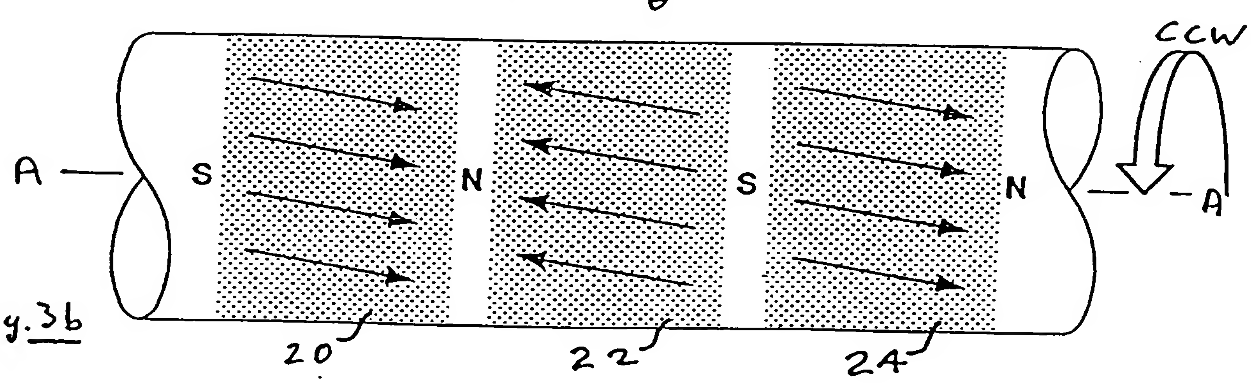


Fig. 3b

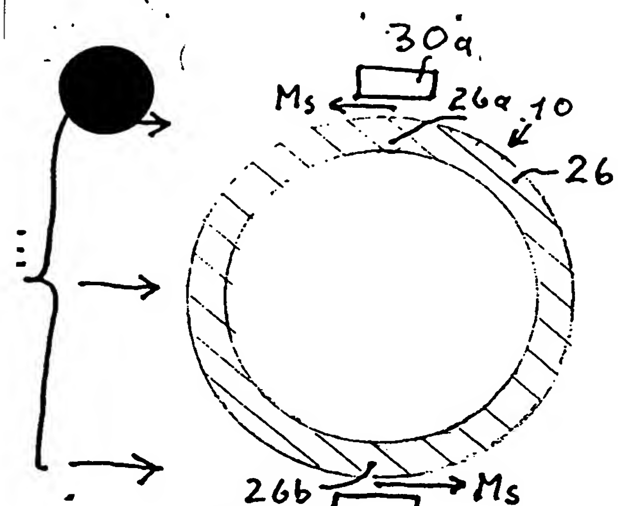


Fig. 2a

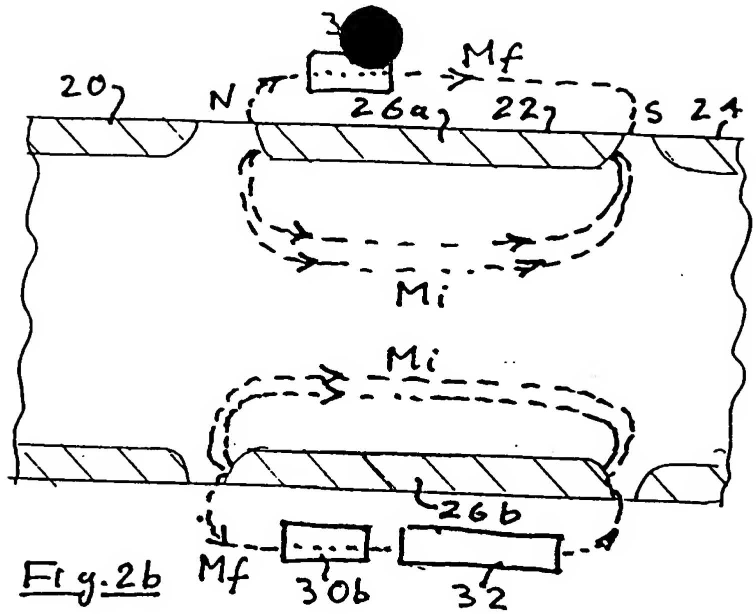


Fig. 2b

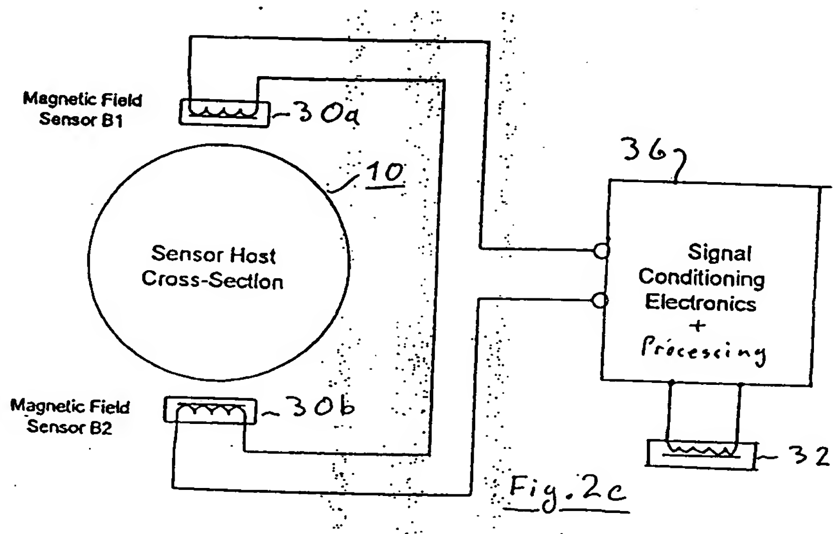


Fig. 2c

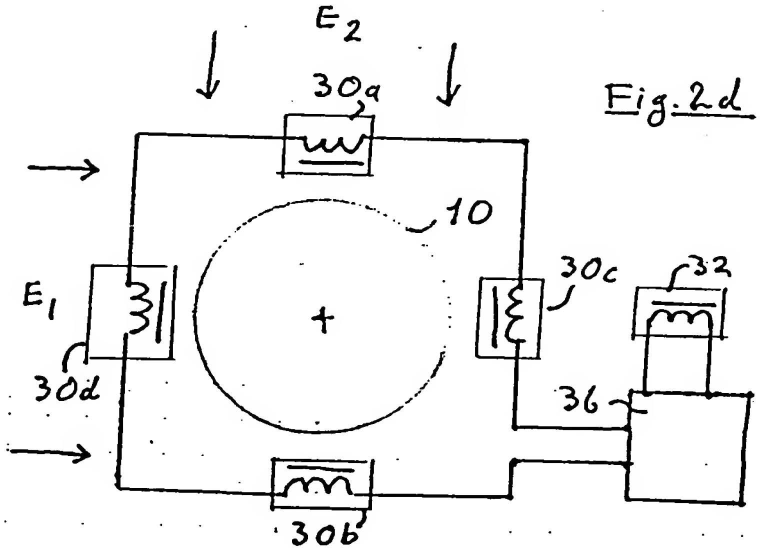
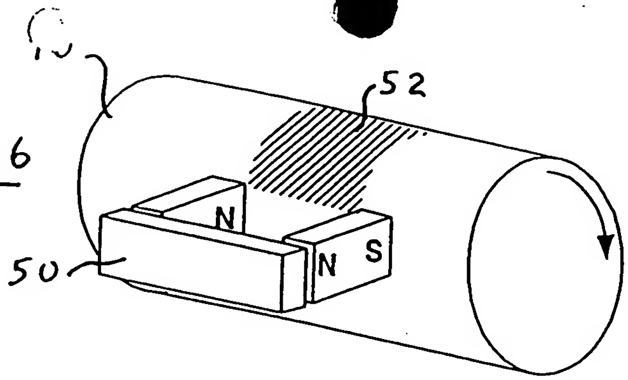


Fig. 2d

Fig. 6



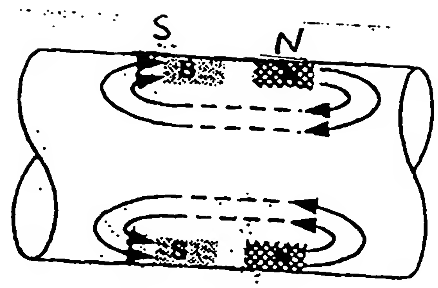


Fig. 7a

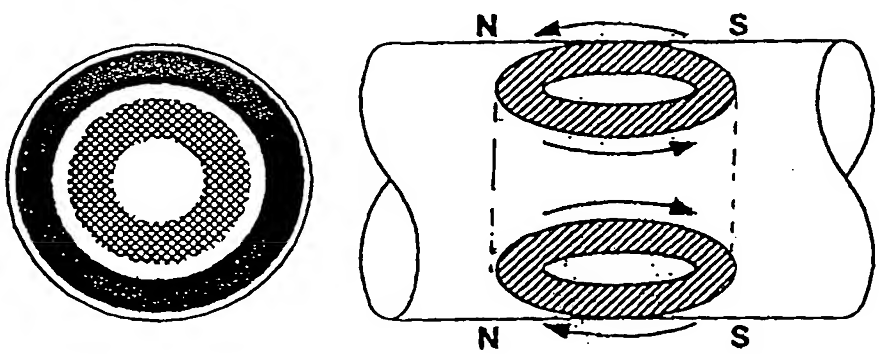


Fig. 7b

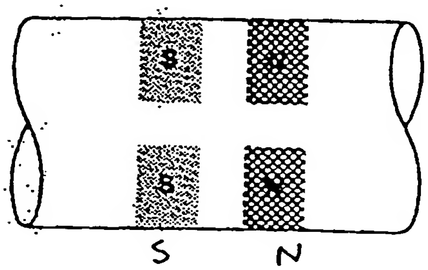


Fig. 8a

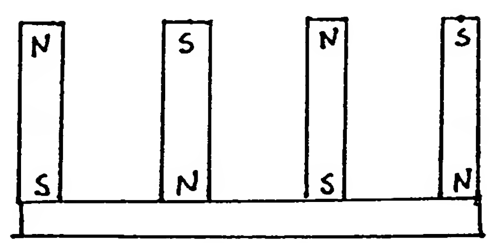


Fig. 6a

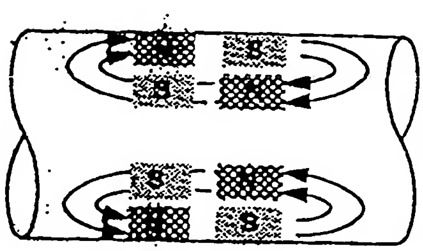


Fig. 8b

Creation of toroid field through second magnetisation process

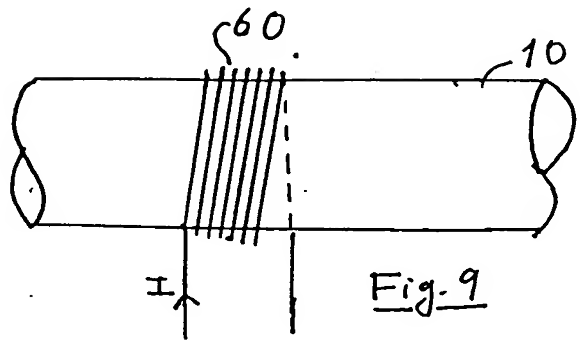


Fig. 9

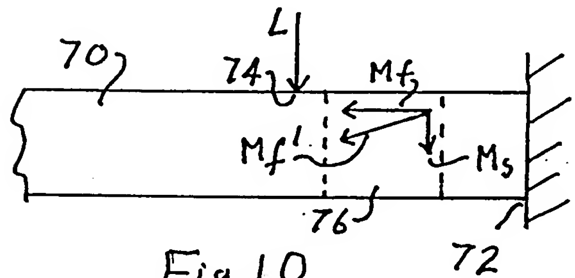


Fig. 10

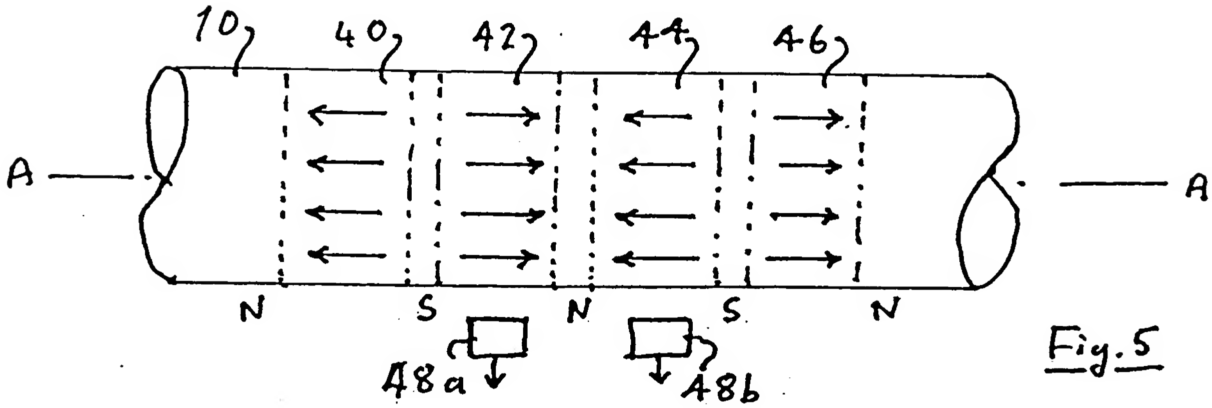


Fig. 5

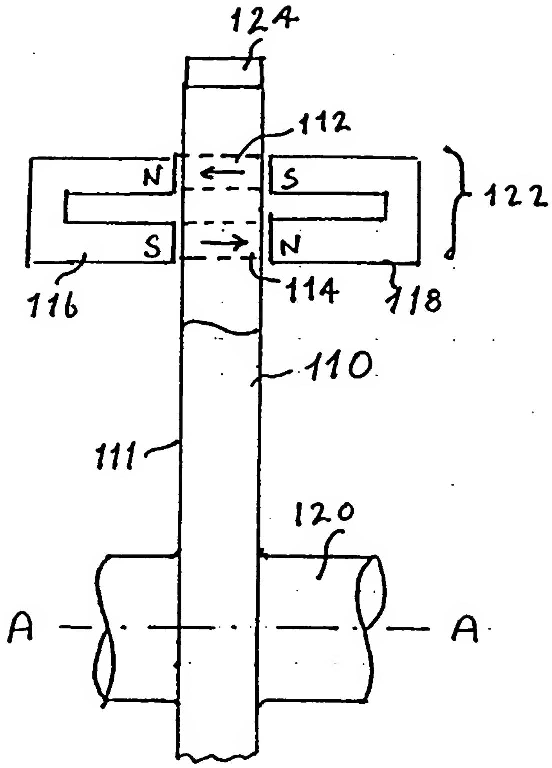


Fig. 11

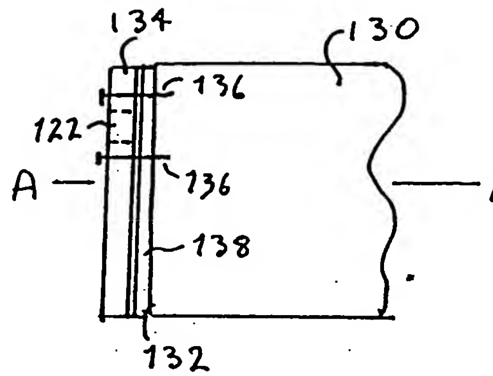


Fig. 14

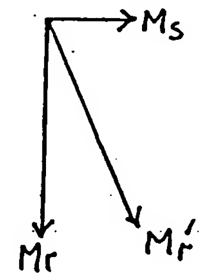


Fig. 13

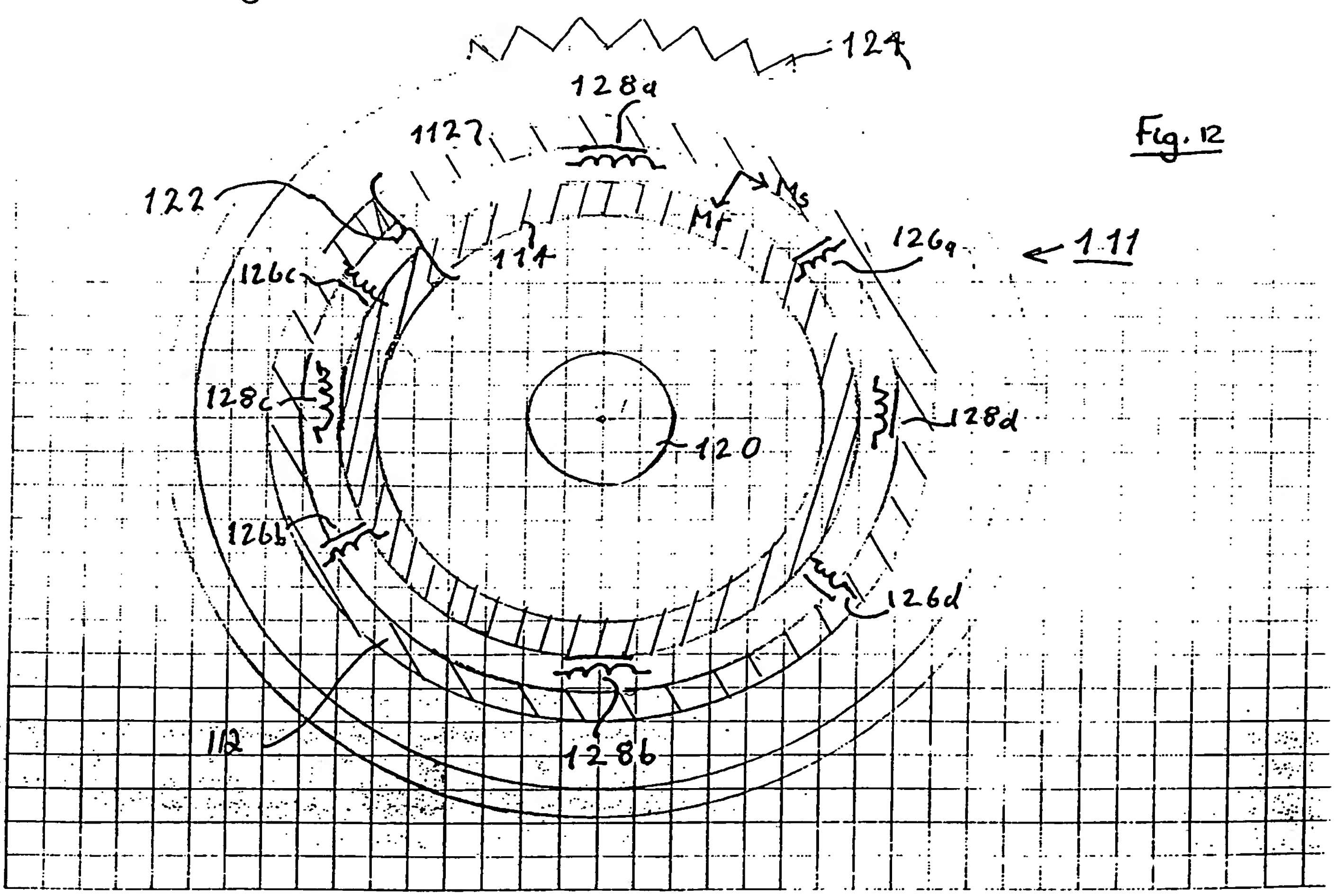
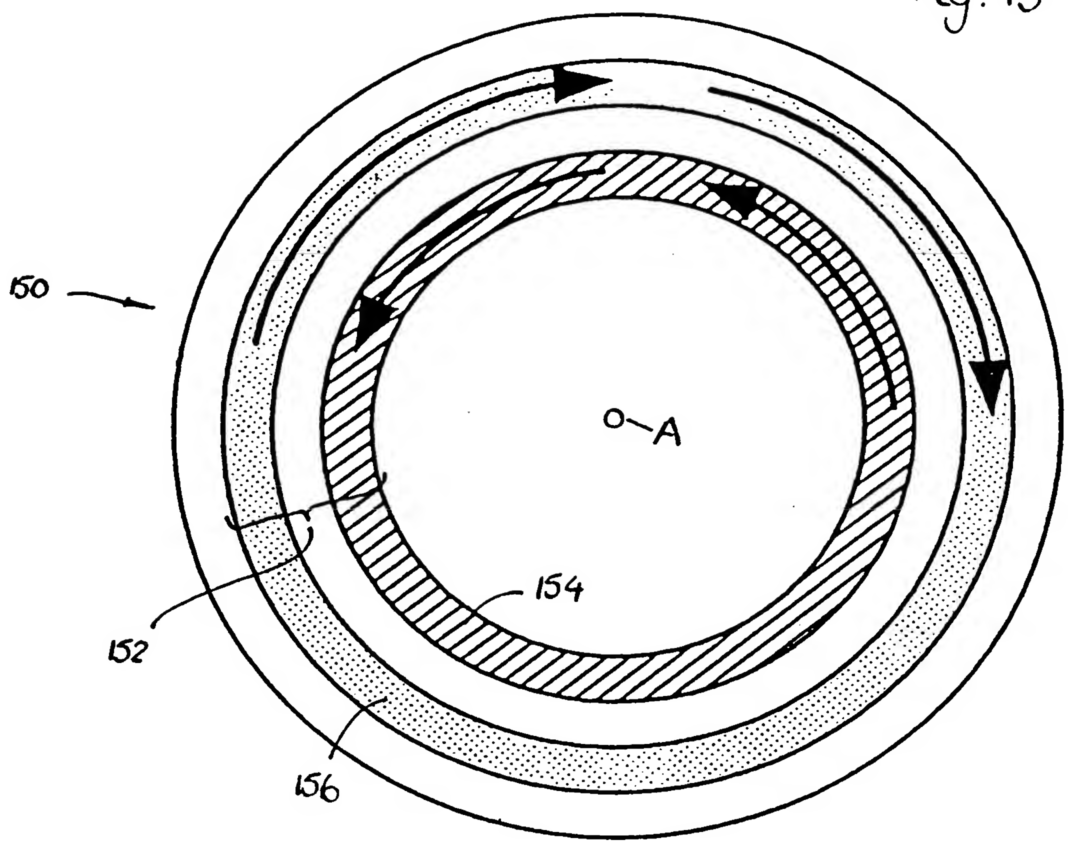


Fig. 12

Fig. 15



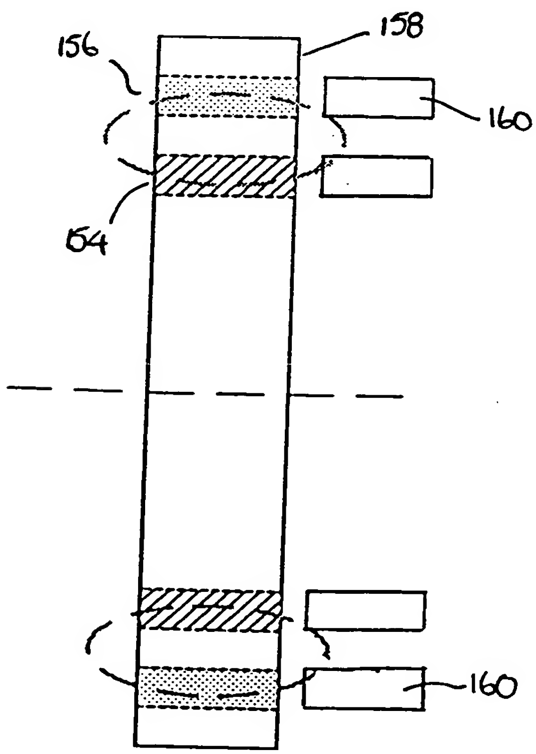


Fig 15a

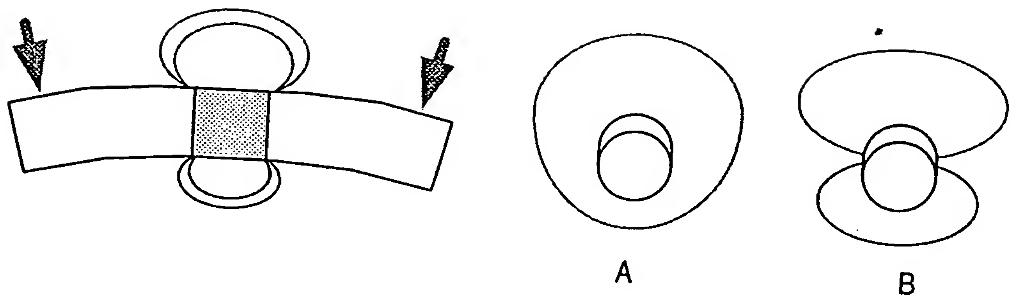


Fig. 16

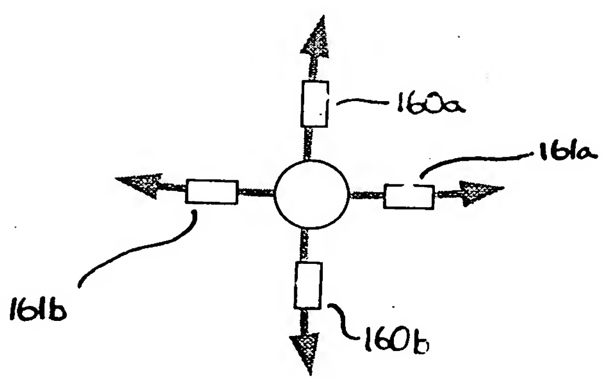


Fig. 17

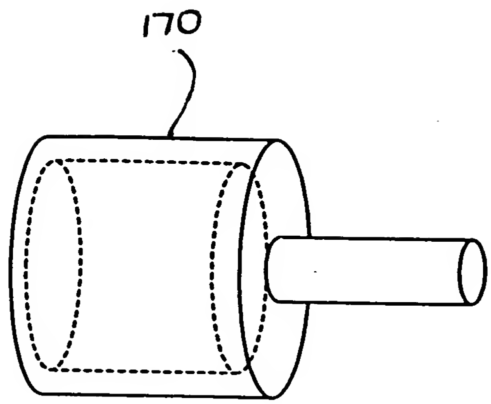


Fig 18a

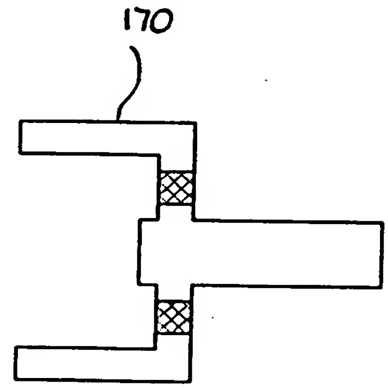


Fig 18b

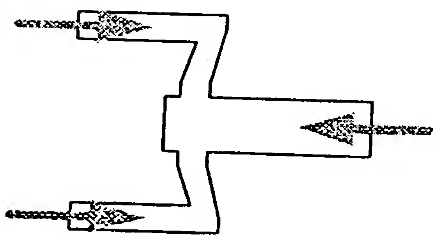


Fig. 19

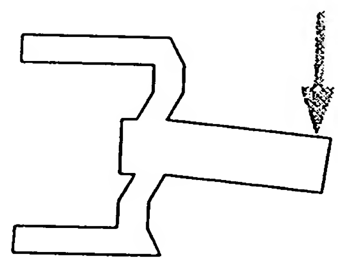


Fig. 20

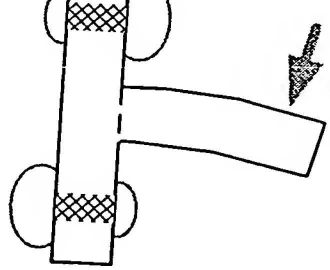


Fig 20a

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